TEST CASE DOCUMENTATION AND TESTING RESULTS

LSTC-QA-LS-DYNA-AWG-ERIF-7-9

TEST CASE ID AWG-ERIF-7

Ballistic Impact on Composite Plate

Tested with LS-DYNA® R10 Revision 116601

Wednesday 19th July, 2017

LSTC
Livermore Software Technology Corp.

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Contents

1 Introduction

1.1 Purpose of this Document

This document specifies the test case AWG-ERIF-7. It provides general test case information like name and ID as well as information to the confidentiality, status, and classification of the test case.
A detailed description of the test case is given, the purpose of the test case is defined, and the tested features are named. The test case specifications also state the target measures for testing and the expected results, as well as their pass and fail criteria.
Testing results are provided in section 5 for the therein mentioned LS-DYNA® version and platforms.

2 Test Case Information

Test Case Summary	
Confidentiality	external use
Test Case Name	Ballistic Impact on Composite Plate
Test Case ID	AWG-ERIF-7
Test Case Status	active
Test Case Classification	Validation
Test Case Source	Boeing UC Berkeley - Mechanical Engineering Department
Tested Keyword	*MAT_COMPOSITE_DMG_MSC, *CONTACT_AUTOMATIC_SURFACE_TO_SURFACE_TIEBREAK, *CONTACT_ERODING_SINGLE_SURFACE_ID
Member of Test Suite	AWG ERIF SUITE
Metadata	AWG ERIF

Table 1: Test Case Summary

3 Test Case Specification

3.1 Test Case Purpose

The purpose of Test Case ID AWG-ERIF-7 is the validation of a steel projectile impact on a 16 ply composite plate. The reliability and consistency of LS-DYNA® as a finite element solver for this impact simulation involving composite structures is evaluated by performing analyses on different cpu architecture platforms and comparison to experimental results.

3.2 Test Case Description

This Test Case contains an impact analysis (see figure 1) with a steel cylinder projectile impacting a 16 ply carbon fiber composite plate. Details on the experimental set up and experimental results can be found in [2].

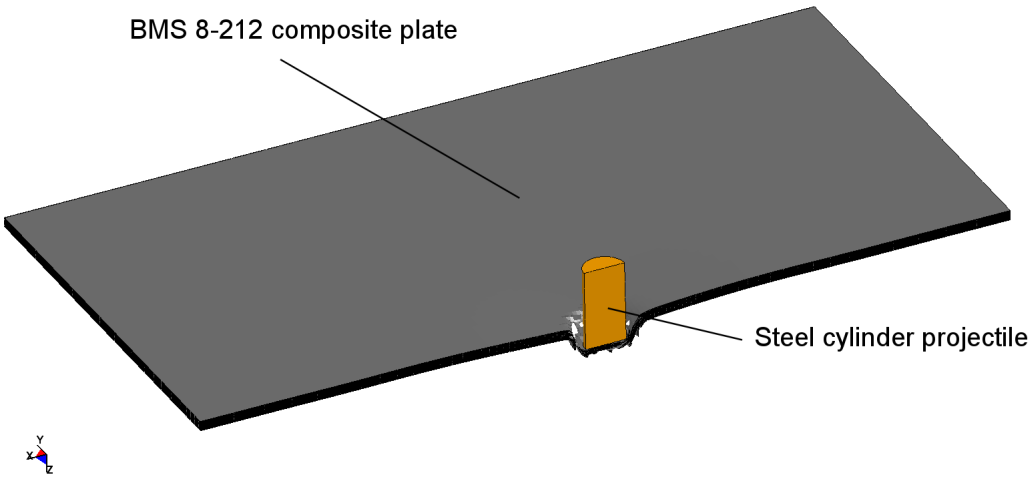

Figure 1: Model sketch: Tool steel cylinder projectile impacting 16 ply BMS 8-212 composite plate

Table 2 contains a short summary of the physical model set up.

Physical Model Information	
projectile geometry	length = 2.0” , diameter = 0.5”
projectile mass	0.082 lb
projectile material	tool steel
projectile initial velocity	4758 in/s
projectile final velocity	4133 in/s
plate geometry	12.0” x 12.0” (clamp frame inside 10” x 10”)
plate material	BMS 8-212
plate material density	0.056 lb per cubic inch
ply orientation	$[0/45/90/-45]_{4s}$

Table 2: Model set-up data

3.3 Model Description

The model geometry is discretized with solid elements for the projectile and for each single ply of the 16 ply composite (see figure 2). Due to symmetry conditions, a half model of the actual geometry is used. Symmetry boundary conditions are applied on the symmetry plane and the outer edges of the composite plate are fully supported. The projectile has an initial z velocity defined on all nodes and is guided along the symmetry plane.
The number of elements and material specifications for the model can be found in table 3 and table 4 reflects the sub test case specification.

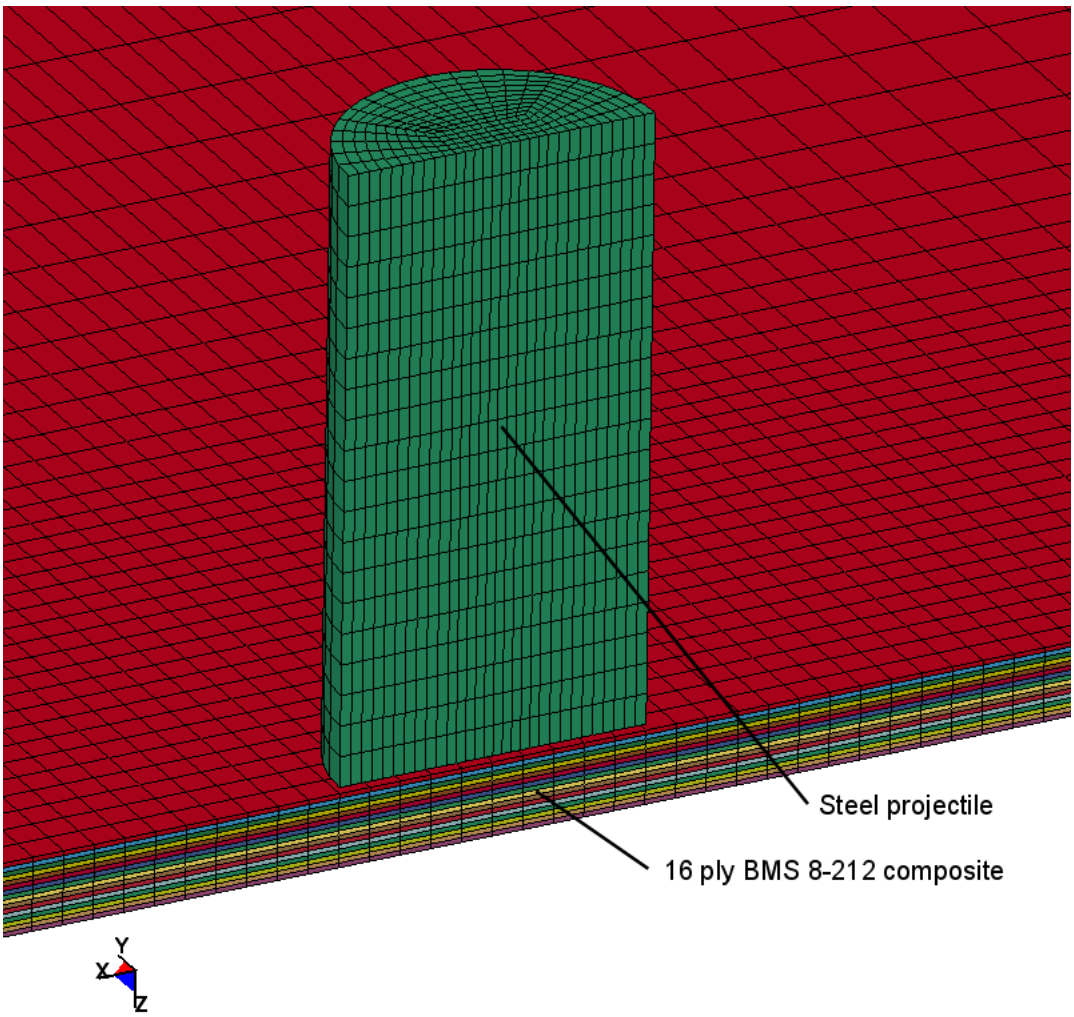

Figure 2: FEA model: Tool steel cylinder projectile impacting 16 ply BMS 8-212 composite plate

The material definitions and their parameters can be found in the input decks.

FEA Model information	
Nodes	122756
Solid elements	61488
Solid materials	17
Parts	17
projectile geometry	length = 1.0” , diameter = 0.5”
projectile mass	0.712E-04 lbfs2/in
projectile material	*MAT_PLASTIC_KINEMATIC
projectile initial velocity	4758 in/s
plate geometry	10.0” x 10.0” x 0.12”
plate material	*MAT_COMPOSITE_DMG_MSC
Units	in (length), s (time), lbf-s^2/in (mass), psi (stress), lbf-in (energy)

Table 3: FEA Model Information

Sub Test Case ID	Input Deck Name
1	aerospace_group_example_07_impact_16_ply_composite.k

Table 4: Specification of sub test cases

4 Test Specifications

4.1 Test Case Targets

Table 5 displays the test case targets. The test case targets specify values or a series of values taken from the finite element analysis solution of the test case and they are used in a comparison of analysis results and experimental data. They are chosen in a way that they can be directly or indirectly compared to the experimentally determined values or observations.

Test Case Targets				
Target number	output	component type	component id	retrieved from
1	internal energy	global	-	binout/glstat file
2	kinetic energy	global	-	binout/glstat file
3	hourglass energy	global	-	binout/glstat file
4	internal energy	part	100 (projectile)	binout/matsum file
5	kinetic energy	part	100 (projectile)	binout/matsum file
6	z-velocity	part	100 (projectile)	binout/matsum file

Table 5: Test Case targets for Test Case ID AWG-ERIF-7

Test case targets one to five are used to evaluate the cross cpu architecture consistency whereas test case target six is used to compare the analysis with the experimental data (see section 4.2).

4.2 Pass/Fail Criteria

These are the Pass/Fail criteria used for the cross cpu architecture consistency and the Validation of the Test Case ID AWG-ERIF-7.

The sub test case passes if the test case target data falls within the corridor bounds. Otherwise the test fails.

The test case corridors are upper and lower bounds for the test case targets. They were defined based on the test target data obtained with LS-DYNA® R9.0 Revision 108899 binaries by the following process:

- For a specific test case target, interpolate the data from different platform and executable (R9.0 Revision 108899) combinations, so that the time domain is the same.
- Calculate the upper and lower bounds of the test case targets 1-2, and 4-6 by:

$$bound_{up}(i) = max(i) + 0.2 \times [max(i) - min(i)] + 0.05 \times peak$$
$$bound_{low}(i) = min(i) - 0.2 \times [max(i) - min(i)] - 0.05 \times peak$$

  Calculate the upper and lower bounds of the test case target 3 (glstat: hourglass energy) by:

$$bound_{up}(i) = max(i) + 0.2 \times [max(i) - min(i)] + 0.05 \times peak$$
$$bound_{low}(i) = min(i) - 0.05 \times peak$$

  where $max(i)$, $min(i)$ are the maximum and minimum values at the i_{th} time step across all platforms and executable (R9.0 Revision 108899) combinations the test case was calculated with, $peak$ is the maximum absolute y value across the whole time domain, $bound_{up}(i)$ and $bound_{low}(i)$ are the upper and lower bounds for the i_{th} time step.
  Note: for the test case target 2 (glstat: kinetic energy), the results obtained on the platform ham with R9.0 Revision 108899 significantly deviated from those obtained on other platforms (sandwich and sgi64e), thus the results from ham were removed from calculating the upper and lower bounds.

5 Test Case Results

5.1 Software and Hardware Specifications

In order to ensure cross-platform consistency, the herein mentioned sub test cases are run on platforms specified in table 6 and the results are calculated with software versions defined in table 7.

Platform Name	Operating system	CPU type	MPI-Protocol	Number of cpu's [1]
mars	CentOS 6.5	Intel® Xeon® E5- 2640 @ 2.50GHz	Platform MPI 8.2.0.0	4
dinar3b	SUSE LES 11	AMD® Opteron ® 6276 @ 2300MHz	Platform MPI 8.2.0.0	4

[1] Number of cpu's used for calculation of the test case

Table 6: Used Platforms and CPU Type's

Product	Version	Release	Revision	Parallel type [1]	Precision [2]	executable
LS-DYNA®	971	R10	116601	SMP	SP	ls971.116601.R10
LS-DYNA®	971	R10	116601	SMP	DP	ld971.116601.R10
LS-DYNA®	971	R10	116601	MPP	SP	mpp971.116601.R10
LS-DYNA®	971	R10	116601	MPP	DP	mpd971.116601.R10

[1] MPP = Massively Parallel Processing, SMP = Symmetric Multiprocessing

[2] SP = single precision, DP = double precision

Table 7: Tested LS-DYNA® version

5.2 Results Summary

Table 8 contains the results of the Test Case ID AWG-ERIF-7 completed with all combinations of software and hardware defined in section 5.1 (1 * 2 * 4 total calculation runs).
Details on the test results can be found in the section 5.3.

The table 8 cross cpu architecture consistency and validation summary is:

- **PASS** - Pass criteria in section 4.2 is attained.
- **FAILED** - Pass criteria in section 4.2 is not attained.
- **ERROR** - sub test case terminates due to error.
- **N/A** - sub test case was not calculated.

Sub Test Case ID	PASS/FAILED
1	**FAILED**

Table 8: Validation results summary for Test Case ID AWG-ERIF-7

5.3 Result Details

The following subsections contain detailed results for the Test Case ID AWG-ERIF-7 for LS-DYNA® R10 Revision 116601.

For each sub test case defined in section 3.3 there is a graph displaying the time history of the result target defined in section 4.1 for the platform and software version combinations defined in section 5.1.

The title of the graph states the test case ID and the name of input deck. The legend contains the result file name, output, platform, executable and number of cpu's separated by comma. A minus sign before the number of cpu's refers to the compatibility option for SMP calculations (see [1] for details on this option).

Example for title and legend:

Title:
'AWG_ERIF_TEST_CASE_7: aerospace_group_example_07_impact_16_ply_composite.k' states the test case ID 7 and name of the input deck for sub test case 1.

Legend:
'glstat_internal_energy,ham,ls971.116601.R10,4' states that the graph shows the internal energy derived from the 'glstat' output file for an input deck which was calculated on the 'ham' platform with a LS-DYNA® R10 Revision 116601 binary (SMP, single precision) on four processors.

5.3.1 Sub Test Case ID 1 - Test Target 1

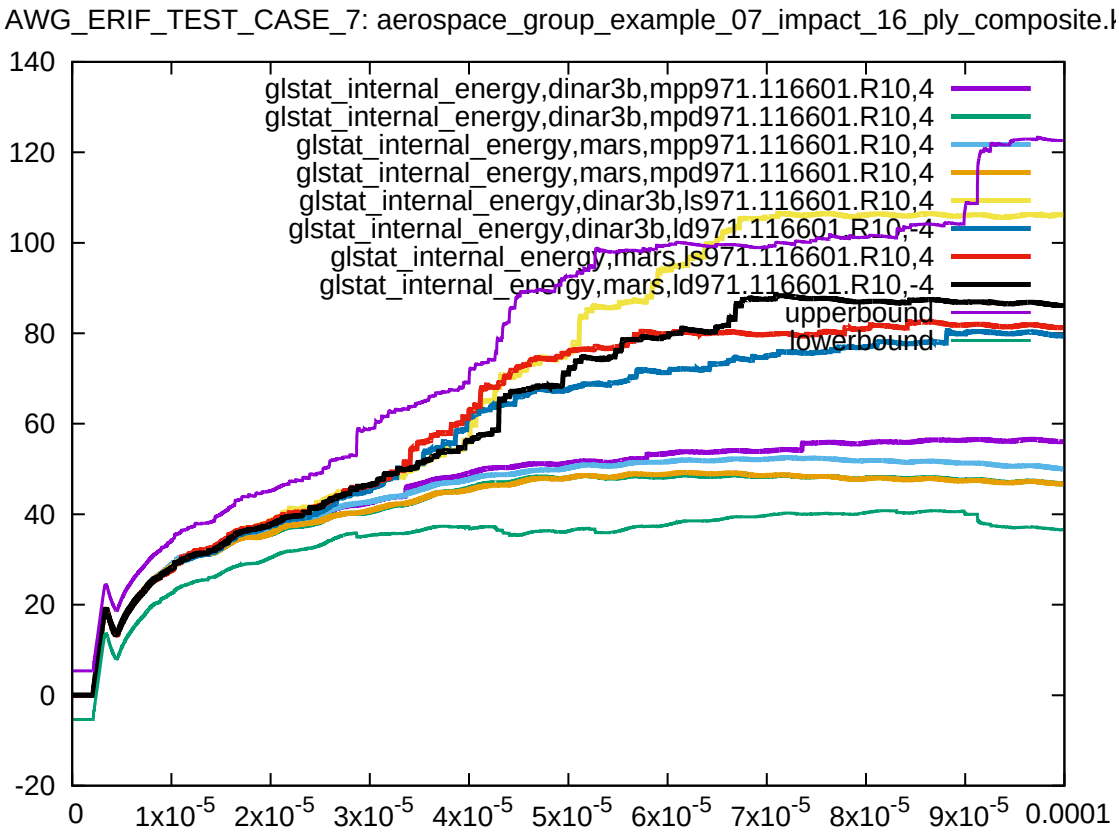

Figure 3: Cross platform results, global internal energy, sub test case ID 1

5.3.2 Sub Test Case ID 1 - Test Target 2

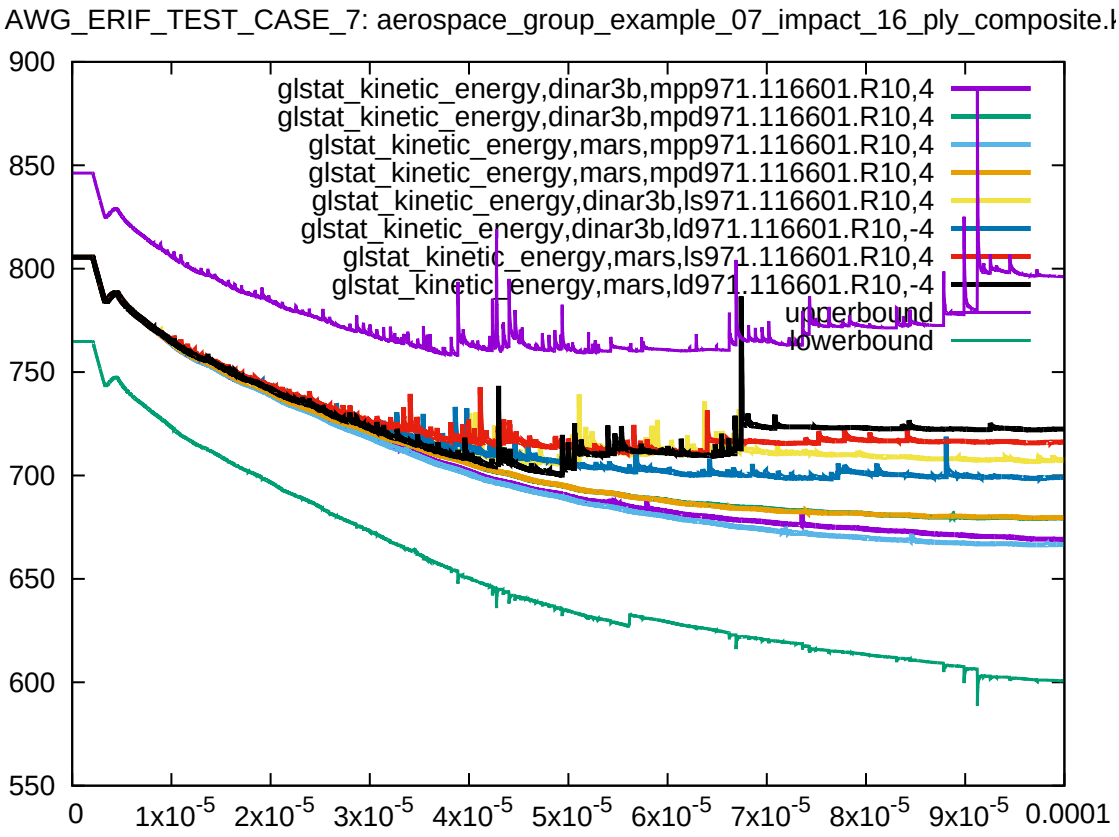

Figure 4: Cross platform results, global kinetic energy, sub test case ID 1

5.3.3 Sub Test Case ID 1 - Test Target 3

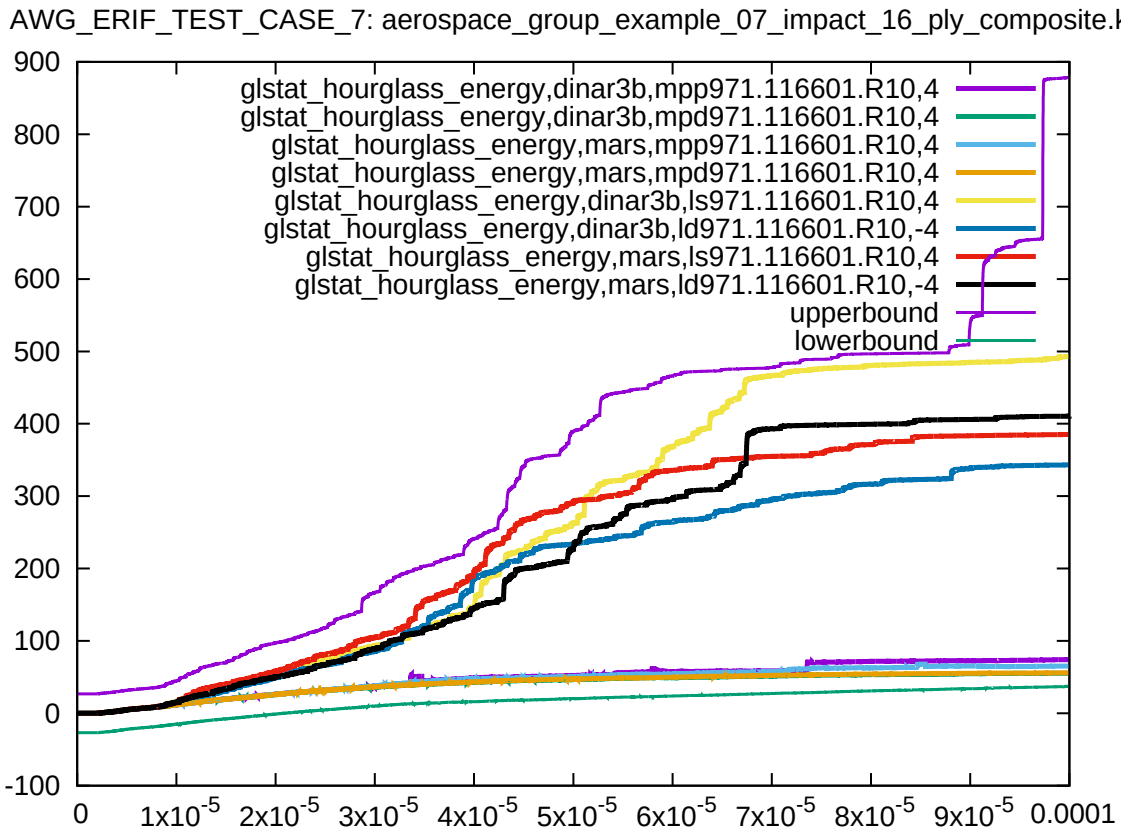

Figure 5: Cross platform results, global hourglass energy, sub test case ID 1

5.3.4 Sub Test Case ID 1 - Test Target 4

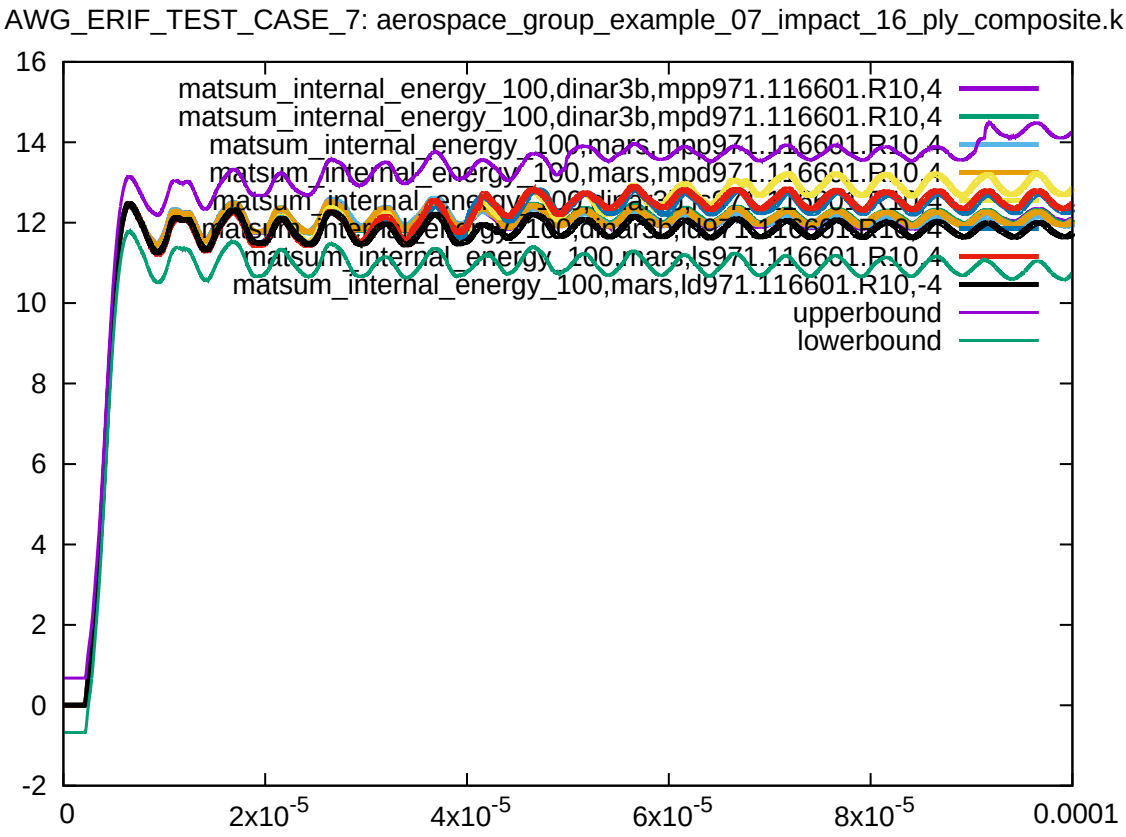

Figure 6: Cross platform results, internal energy part 100, sub test case ID 1

5.3.5 Sub Test Case ID 1 - Test Target 5

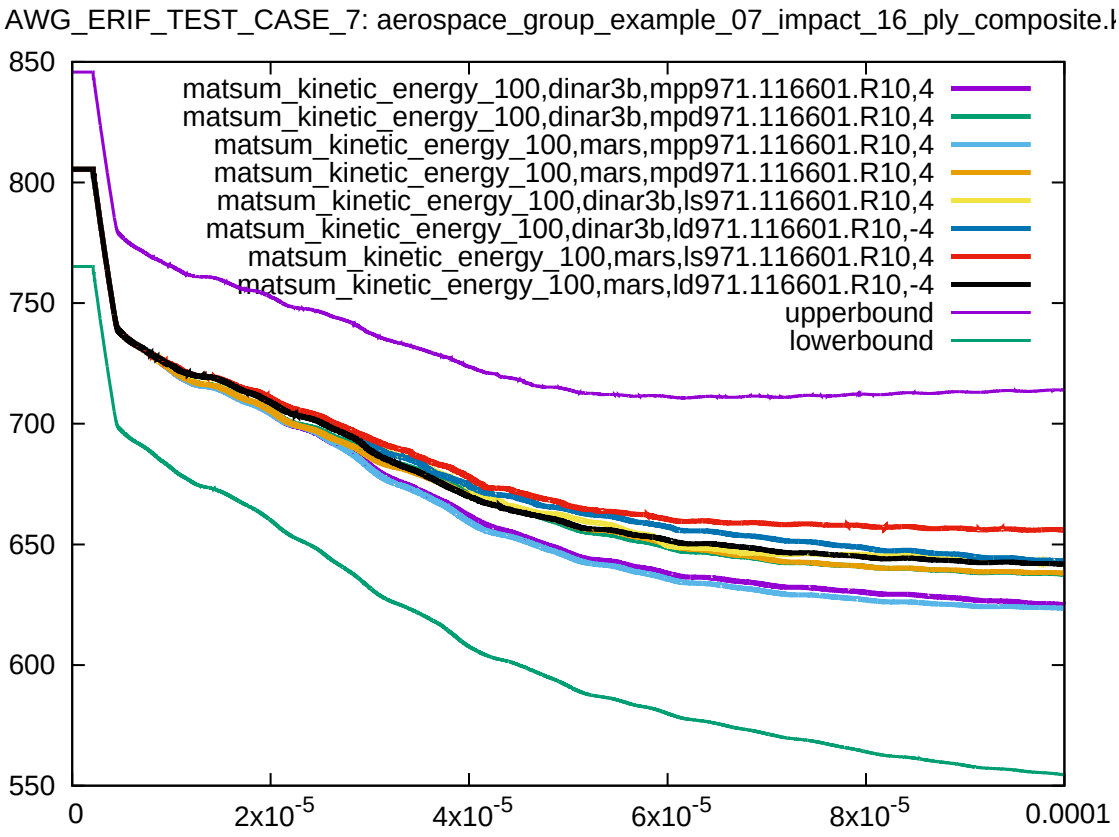

Figure 7: Cross platform results, kinetic energy part 100, sub test case ID 1

5.3.6 Sub Test Case ID 1 - Test Target 6

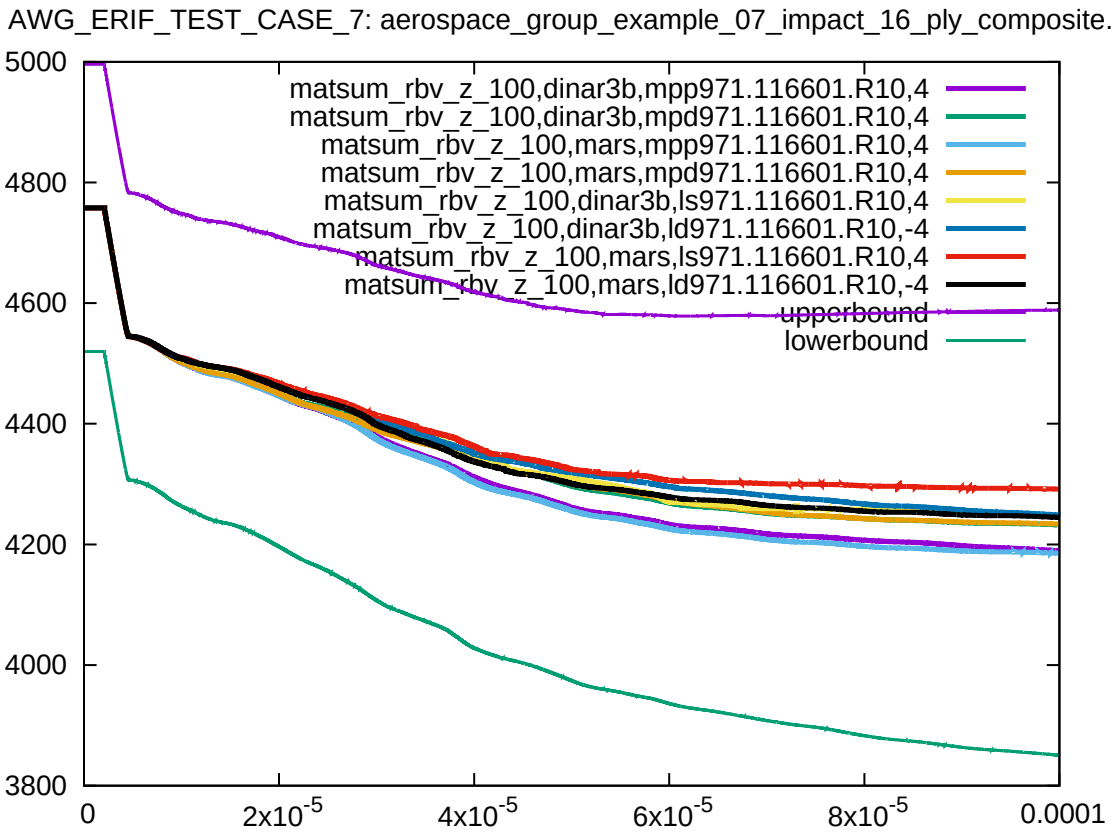

Figure 8: Cross platform results, z-velocity part 100, sub test case ID 1

References

[1] LSTC, *LS-DYNA KEYWORD USER MANUAL*, 7374 Las Positas Road, Livermore, CA, 94551, USA, version 971 ed., May 2007.

[2] D. POWELL, T. ZOHDI, AND G. JOHNSON, *Impact and Delamination Failure Characterization of BMS 8-212 Air Traffic Organization*, Final Report DOT/FAA/AR-08/48, U.S. Department of Transportation, Federal Aviation Administration, Office of Aviation Research, Washington, D.C. 20591, October 2008.